(200)
Un3tpi

73-260

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

PROJECT REPORT
Pakistan Investigations
(IR) PK-32

RECONNAISSANCE EVALUATION OF PAKISTAN FOR PHOSPHATE ROCK

by

R. P. Sheldon
U. S. Geological Survey

73-260

OPEN FILE REPORT

This report is preliminary and has not been edited or reviewed for conformity with Geological Survey standards or nomenclature

Prepared under the auspices of the Government of Pakistan and the Agency for International Development U. S. Department of State

1973

RECONNAISSANCE EVALUATION OF PAKISTAN FOR PHOSPHATE ROCK

by

R. P. Sheldon
U. S. Geological Survey

CONTENTS

ILLUSTRATION

RECONNAISSANCE EVALUATION OF PAKISTAN FOR PHOSPHATE ROCK

By R. P. Sheldon
U. S. Geological Survey

INTRODUCTION

Geologists of the Geological Survey of Pakistan and the U. S. Geological Survey have been vitally concerned with phosphate exploration in Pakistan for several years, and preliminary exploration has revealed several localities of phosphate rocks. From April 9 to May 5, 1966, I visited the Geological Survey of Pakistan to assist in phosphate exploration and to evaluate in a preliminary way phosphate localities already located.

As a result of recent discoveries in the Middle and Far East, it is known that phosphatic horizons of probable economic potential are present on both sides of Pakistan in India and Iran. Thus it is very worthwhile to thoroughly explore Pakistan for phosphate in the hope that one of these horizons extends into the country or that new horizons can be found. The Cretaceous-Tertiary phosphogenic province of North Africa and the Middle East extends into the Zagros Mountains of Iran and the Persian Gulf area and could extend farther east into Pakistan. Jurassic phosphorite is present in the basal part of the Tal Series in the foothills of the Himalayas in Uttar Pradesh, India, and rocks of more or less the same age and lithology extend westward into Pakistan. Finally, lower Paleozoic (pre-Permian) phosphorite has been found southwest of Jaiselmer, Rajasthan, in India only a few kilometers from the India-Pakistan border. A preliminary evaluation of the possibility that these phosphatic horizons extend into Pakistan is discussed below, along with an evaluation of the already found phosphatic localities. This report describes conditions as of 1966.

Acknowledgements

The scientific association and personal friendship with Mr. S. T. Ali and Mr. A. N. Fatmi of the Geological Survey of Pakistan not only made the work in Pakistan most enjoyable but also insured the success of the reconnaissance. The support of Dr. A. F. M. M. Haque, the Director-General of the Geological Survey of Pakistan, made the project possible, and his encouragement and enthusiasm greatly stimulated the effort. All of my colleagues in the Geological Surveys of Pakistan and the United States were most helpful when called on, and their aid is greatly appreciated. The project was sponsored by the Agency for International Development, U. S. Department of State.

TECHNIQUES OF PHOSPHATE EXPLORATION

It is beyond the scope of this report to describe in full the modern techniques of phosphate exploration. They have been dealt with in papers by McKelvey (1963) and Sheldon (1964a, 1964b). These techniques are based mainly on the identification of ancient geologic environments similar to the geologic environment in which phosphate is being formed today. Analysis of tectonic elements gives valuable clues to the presence of phosphate because of their influence on sedimentation. Apatite is deposited slowly in moderately deep water open to the ocean, or at least on shelves adjacent to such moderately deep seaways, and miogeosynclines adjacent to cratons offer the best chance of finding such an environment. Phosphate generally forms in condensed stratigraphic sequences within the miogeosyncline. On the other hand, basins of rapid sedimentation are unfavorable because rapid chemical or clastic sedimentation masks or disperses the slowly deposited apatite, so that eugeosynclines are unlikely to contain significant phosphate deposits. Also, restricted basins or intracratonic basins offer only a slight chance for phosphate deposits because the oceanic supply of phosphorus to the sediments is in general insufficient for the deposition of an appreciable quantity of apatite.

Once a suitable tectonic environment has been identified, the rock suites present offer help in locating phosphate deposits. Organic matter and silica (which diagenetically alters to chert) are genetically associated with apatite as a result of their common origin from cold upwelling ocean currents. On the other hand, warm-water sediments, such as coral reefs and oolitic limestone, are not directly associated with phosphate either in the ocean today or in ancient rocks, even though they are deposited in the same latitudes or paleolatitudes (Sheldon, 1964b). One must use this association of rock suites carefully, however, as not all and probably not even most chert is associated with phosphate; much chert is of volcanic origin. Volcanic chert commonly is made up of or contains warm-water siliceous organisms, such as Radiolaria, whereas the chert associated with phosphate is made up of cold-water siliceous organisms such as diatoms or siliceous sponge spicules, depending on the age. Also, not all organic matter is associated with phosphate. Finally, not all phosphate is associated with chert and organic matter, although most of the world's reserves have this association. If used with discretion, however, the black shale-chert-phosphorite association furnishes a powerful tool for phosphate exploration.

The ubiquity of apatite in sedimentary rocks presents a problem to phosphate exploration in that one has to make judgments on the potential of minor amounts of apatite. Small amounts of nodular pelletal, fossiliferous, and structureless apatite are found in many kinds of sedimentary rocks. Understanding of such deposits is far from complete, as not enough research on their origin has been done. One common type of so-far noncommercial phosphate is found in lagoonal or restricted sea sediments and is more or less associated with sedimentary iron. Because of the restricted nature of the sedimentary environment, the source of such apatite appears to be from streams entering the lagoon or restricted sea, and this source seems to be insufficient for deposition of a significant quantity of apatite. On the other hand, the feather edge of an economic bed of phosphate rock may appear similar to one of these minor deposits of phosphate. Therefore, any horizon of phosphate must be studied to the point that its economic potential can be evaluated, either theoretically (for example, if it can be shown to be a lagoonal phosphorite) or empirically by trenching and sampling. The former is risky in that our knowledge of the geology of economic phosphate deposits is incomplete, but such judgments can be helpful in deciding priority of investigation.

POSSIBILITY OF CRETACEOUS-TERTIARY PHOSPHATE ROCK IN PAKISTAN

The Cretaceous-lower Tertiary rocks deposited along the southern margin of the Tethys Sea contain phosphate rock deposits from Morocco to Iran (Sheldon, 1964a, 1964b). This former sea was open to the ocean, was relatively deep, and probably was the site of upwelling ocean currents flowing westward. The phosphate deposits are localized in minor basins, within the main trough, so that synsedimentary tectonics exerted a strong control to deposition. Generally speaking, phosphate deposits are found in the marginal trough or miogeosyncline, which lies just to the north of the Afro-Arabian craton, and which is bounded on its north by a geanticline. North of the geanticline is the internal trough or eugeosyncline, which, because of rapid sedimentation contains no economically important phosphate deposits. The phosphate deposits are found in starved basin stages of evolution of the miogeosynclines and adjacent parts of the craton.

In West Pakistan, similar tectonic provinces can be found. The tectonic elements trend north-northeast in most of West Pakistan but curve to a more or less east-west orientation in southwestern West Pakistan. Going across the structural strike from southeast to northwest are, successively, the Indian craton, the Indus miogeosyncline, the axial belt or geanticline, and the eugeosyncline. The latter three elements are a part of the Baluchistan geosyncline (fig. 1). All these elements are apparently continuations of similar elements in Iran, although the cover of the Arabian sea makes correlation of the southeastern elements tenuous (Hunting Survey Corp. Ltd., 1960, p. 385-399).

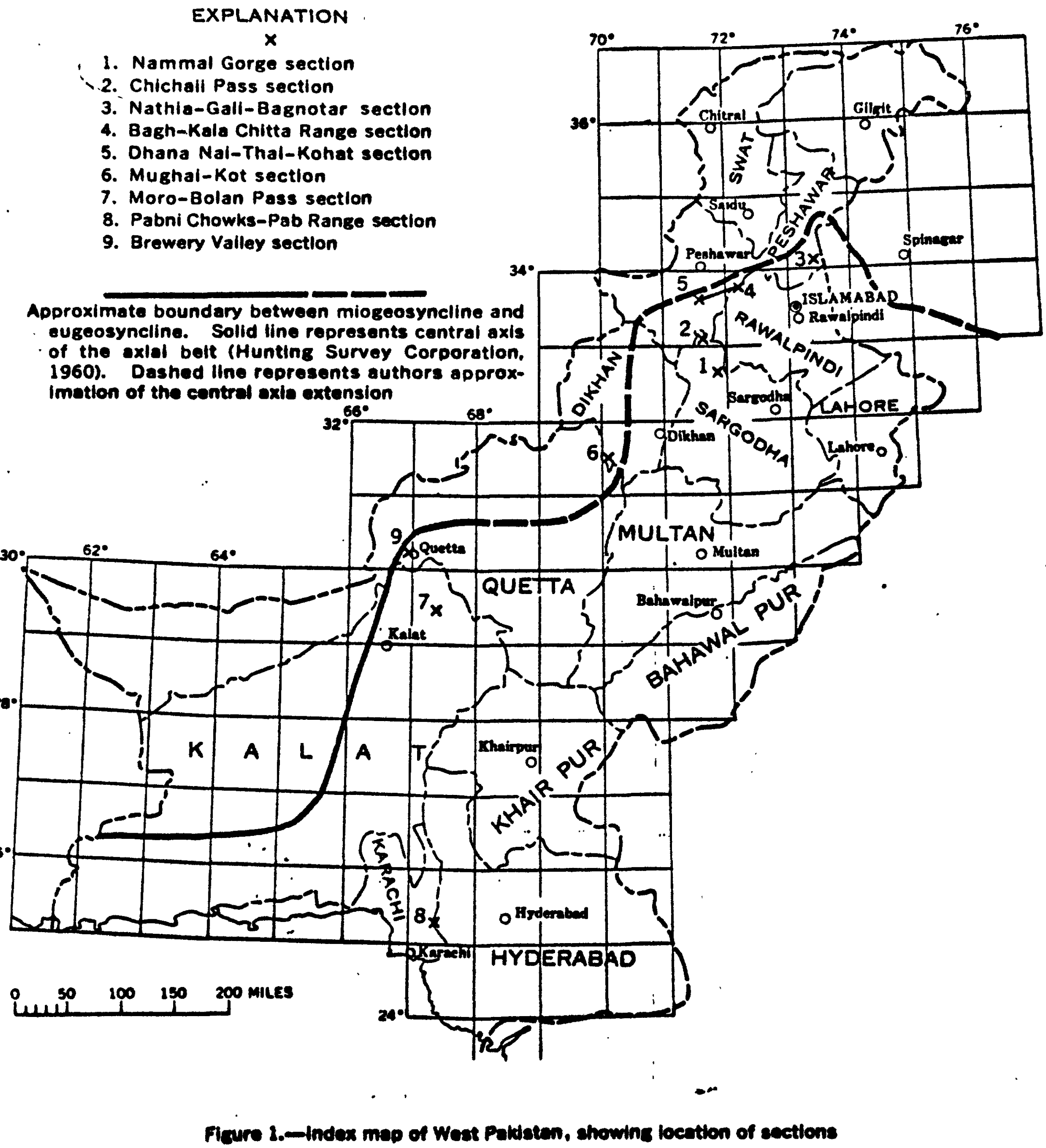

Figure 1.—Index map of West Pakistan, showing location of sections

An important difference exists, however, between the West Pakistan tectonic elements and their Middle Eastern counterparts. It appears that in the Indus miogeosyncline during the Tertiary and Cretaceous, sedimentation always kept pace with subsidence, so that even though it was the site of marine sedimentation, the seas were always shallow. On the other hand, the eugeosyncline in West Pakistan contains thick, dark, organic-rich shales as a part of the flysch sequence, in contrast to the thick brownish shales that are not particularly rich in organic matter in the Middle Eastern eugeosyncline.

In terms of phosphate geology, these differences may be critical. For formation of significant deposits of phosphate, relatively deep seas that receive only small amounts of sediment and that are connected with the open ocean must be present. This is to allow the action of upwelling ocean currents as well as a sufficient source of phosphorus. If it is really true that the Indus miogeosyncline had no deep-water starved basin stage of development in Mesozoic and Tertiary time, it is difficult to see how significant phosphate deposits could be formed. Conversely, the presence of abundant organic matter in the eugeosyncline may indicate that upwelling was occurring there where sedimentation was rapid, and not in the miogeosyncline where sedimentation was relatively slow. These are the general conclusions I came to after a brief study of the literature, discussions with various geologists, and the brief reconnaissance. It should be emphasized that this program has been far from exhaustive and important facts may have been missed, but at least the path of future exploration is clear. One should search for exceptions to these generalizations. Some of the field evidence for the conclusions is presented below.

Because of limited exposures, only sections of miogeosynclinal Cretaceous and lower Tertiary rocks on the western side of the Indus miogeosyncline or exposed along the flanks of the axial belt could be examined in West Pakistan. These rocks are covered in the axial parts of the Indus geosyncline. However, I had the opportunity to examine the rocks on the east side of the geosyncline while working on a similar project in India. It is very difficult to separate the various tectonic facies in the area we reconnoitered. The Canadian geologists working under the Colombo plan program made such distinctions in southwestern West Pakistan, and it seems likely that such distinctions will be made in the rest of West Pakistan (Hunting Survey Corp. Ltd., 1960) when the work is carried farther. Thus the classification I have made is preliminary and perhaps premature.

Lower Tertiary rocks

The miogeosynclinal Tertiary rocks were examined in the Nammal Gorge section of the western Salt Range (fig. 1). They included from base to top the following formations: the Sakessar Limestone, Nammal Formation, Patala Formation, Lockhart Limestone, and the Dhak Pass Formation. As exposures of these formations were excellent, very few beds were missed because of cover. The section contains several dark-shale units, one of which, the Patala Formation, contains rare scattered slightly phosphatic nodules. The Nammal Formation and the Lockhart Limestone contain limestone in which are scattered chert nodules. The presence of the dark shale and chert at first glance gives some encouragement to the prospects of finding phosphate rock, but careful examination of the section revealed nothing more than the scattered, slightly phosphatic nodules in the Patala Formation. I agree completely with Mr. Fatmi's statement, "The littoral environment of the Dhak Pass Formation, the warm shallow rather restricted waters of the Lockhart limestone, the lagoonal shallow water of the Patala Shale, and the open but shallow seas of the Nammal Formation and Sakessar Limestone do not offer good chances of finding phosphates."

The eugeosyncline Tertiary section was examined in the Sulaiman Range west of Dera Ismail Khan (fig. 1). It includes about 12,000 feet of Eocene formations, which are, from top to base, the Drazinda Shale, Pir-Koh Limestone, Domanda Shale, Habib Rahi Limestone, Baska Shale, and the Ghazij Shale. The Paleocene rocks are 340 feet thick and are all included in the Dunghan Limestone. Because of its large thicknesses and clastic nature, much of this section was not examined, but the Habib Rahi Limestone was examined in detail. It consists of thin-bedded limestone rich in organic matter and containing chert beds. A detailed examination revealed scattered phosphatized fish and remains of other organisms, but no evidence of bedded/ phosphorite. It appears that the environment of deposition of the Habib Rahi Limestone was restricted marine or perhaps brackish water, and if so the chance of finding economic phosphate rock is negligible. However, the presence of oil shale, chert, and phosphatized fish remains makes a more detailed study of this formation desirable, both for its phosphate potential and its oil-shale potential.

In summary, the Tertiary rocks of West Pakistan, where examined, do not offer much potential for phosphate, except perhaps for the Habib Rahi Limestone. Deposition was too shallow for the accumulation of large quantities of phosphate in the Indus geosyncline, a supposition substantiated by the shallow-water marine section of lower Tertiary rocks in western Rajasthan, India. In the eugeosyncline, deposition was too rapid for the concentration of phosphate deposits.

Cretaceous rocks

Cretaceous rocks were examined at more localities than any other systems in West Pakistan, mainly because phosphate had already been located in several places in Cretaceous rocks, but also because the phosphate in the Persian Gulf subsurface in Iran is of Cretaceous age. The miogeosynclinal rocks were examined in the Chichali Pass section, the Nathia-Gali-Bagnotar section, the Bagh-Kala Chitta Range section, the Moro-Bolan Pass section, the Brewery valley section, and the Pabni Chowks-Pab Range section (fig. 1). The eugeosynclinal rocks were examined in the Dhana Nai-Thal-Kohat section and the Mughal Kot section (fig. 1).

Although the stratigraphy of the Cretaceous rocks of the Indus miogeosyncline of West Pakistan is fairly complex, the rocks themselves are fairly uniformly warm shallow-water in origin, judging by their fauna and lithology. Oolitic limestone, well-sorted sandstone, variegated shale, and iron-rich shale are common. Corals and a rich shelly fauna are also fairly common. In addition the Cretaceous rocks in the miogeosyncline are relatively thin. Because no evidence was seen for a deep starved-basin stage of evolution, followed by filling up of the basin resulting in thicker deposits, the phosphate potential of these rocks seems low.

In the Bagh-Kala Chitta Range section, phosphate was found by geochemical testing of the limestone at the upper contact of the Lumshiwal Sandstone. This phosphatic horizon lies disconformably beneath the Kawagarh Formation, which consists of light-colored thin-bedded marl. The phosphate is calcareous and has the same texture as the limestone, and it is impossible to distinguish from the limestone without chemical testing. It is highly lenticular and variable in grade. Apparently it formed as a replacement of the limestone, as suggested both by the texture and stratigraphic position just below the disconformity. It certainly is not a normal sedimentary marine phosphorite. It seems unlikely that this horizon is the feather edge of a larger marine phosphorite unit; however, the fact that the rock in places contains as much as 15 percent P_2O_5 and is as much as 2 feet thick makes it desirable to further investigate the deposit. The rock found so far is so fine grained that separation of the apatite from the calcite is not possible, and the calcite content is certainly too high to make superphosphate fertilizer from the rock. Thus, better-grade material must be found in order to obtain commercial rock from the deposit.

In the Moro-Bolan Pass section, the Moro Formation was studied with care. It consists of a dark shale unit underlain by a cherty limestone, possibly deposited in a marine environment of upwelling waters. However, examination of the outcrop revealed no phosphate in the shale unit. The chert is secondary in origin as shown by its texture and structure. The limestone is in part oolitic and contains corals. This along with the limited extent suggests that the dark shale was deposited in a restricted marine environment not favorable for the occurrence of phosphate rock.

In the Pab Range section, the Karara Shale is a dark unit containing nodules of chert, some of which are known to be slightly phosphatic. Reconnaissance of the section revealed no beds of phosphate rock. The abundance of limonite or hematite in the nodules suggests a nearshore environment and a genetic relation between the silica, iron, and phosphate, and makes the Karara Shale unattractive for phosphate. This relation is discussed in detail below in dealing with the Chichali Formation of Jurassic age.

The Cretaceous rocks of the eugeosyncline are probably represented in the Mughal Kot section, where they consist of a very thick sequence of dark shale, limestone, and sandstone. Some sole markings were observed at the base of a thin sandstone intercalated in black shale; probably at least part of the sequence is a turbidite. Deposition was very rapid and the chances of finding phosphate rock in the turbidite seem slim. However, near the base of the sequence there may be a condensed section containing phosphate rock, representing an early, deep-water, starved-basin stage of development of the geosyncline, followed by rapid flysch sedimentation. In the beautifully exposed section along the gorge, no evidence for such a condensed section was seen, and no phosphate rock was found, but easily could have been missed in the rapid reconnaissance.

In summary, the Cretaceous rocks of West Pakistan were deposited in much the same sort of geologic environment as the lower Tertiary rocks. It appears that in the miogeosyncline the seas were too shallow and restricted for significant phosphate deposition, and in the eugeosyncline deposition was too rapid for phosphate concentration. For these reasons, it would seem that the lower Tertiary-Cretaceous phosphogenic province does not extend into West Pakistan, although further work along these lines must be done for definite proof.

POSSIBILITY OF JURASSIC PHOSPHATE ROCK IN PAKISTAN

The discovery of phosphate rock in Jurassic rocks in the Himalayan foothills of Uttar Pradesh, India, increases the chances of finding phosphate in rocks of the same age in northern Pakistan. There was insufficient time to reconnoiter the area most likely to contain such rock near Devigahr and Udhampur in southwestern Kashmir; however, Jurassic rocks were studied in the Nammal Gorge section, the Chichali Pass section, the Nathia-Gali-Bagnotar section, the Bagh-Kala Chitta Range section, and the Mughal Kot section (fig. 1).

The Jurassic facies studied that is most similar to the Uttar Pradesh Formation is the Spiti Shale exposed in the Nathia-Gali-Bagnotar section. However, a traverse of these rocks revealed no phosphate and also no chert, which is associated with the phosphate in India. The time spent in the traverse was quite short, and many other localities remain to be studied, so the possibility of locating phosphate in Jurassic rocks in this area still exists.

In the Nammal Gorge and Chichali Pass sections of the western Salt Range and in the Bagh-Kala Chitta Range section (fig. 1), the facies are much different from that of the Spiti Shale. Variegated shale of the Datta Formation represents the Jurassic in Nammal Gorge, and the Samana Suk Limestone and Chichali Formation represent the Jurassic in Chichali Pass and the Kala Chitta Range. All these rocks appear to be shallow-water, restricted marine to brackish-water deposits, and not prospective for economic phosphate. The Chichali Formation is made up of dark shale rich in belemnite remains, chamosite, and glauconite beds. Some of the dark shale beds contain scattered apatite nodules. These nodules are as much as 0.5 foot in diameter, but most range between 1 and 3 inches in diameter. The nodules commonly contain glauconite or chamosite grains and make up less than 1 percent of the shale unit. It is probable that this unit was deposited in somewhat restricted waters and that the phosphate as well as the iron was supplied by streams entering the area of sedimentation. The presence of chamosite is particularly significant in this regard, as it is not a normal marine sediment, but very likely a brackish-water sediment. If this is true (and in order to prove it more physical stratigraphy would have to be worked out), it is unlikely that enough phosphate was introduced to cause the deposition of significant quantities of phosphorite. Moreover, the abundance of iron and aluminum make the phosphate unsuitable as a fertilizer raw material, and the scarcity of the nodules in the shale makes them uneconomic for mining.

In the Mughal Kot section in the Sulaiman Range, the Jurassic System is represented by the very thick Sulaiman Limestone. This limestone underlies the eugeosynclinal Cretaceous flysch, and represents a somewhat more stable stage of development of the geosyncline. The rate of sedimentation of the Sulaiman Limestone was high and seems to rule out any possibility of economic phosphate. As mentioned above, the contact between the limestone and the overlying shale was carefully examined for evidence of phosphate sedimentation, but none was found. However, this contact probably should be examined in several other localities for such evidence.

POSSIBILITY OF PERMIAN PHOSPHATE ROCK IN PAKISTAN

In the Salt Range, rare scattered nodules have been found between Middle and Upper Permian rocks. This section of rock in addition contains a few nodules and lenses of secondary chert. But it also contains fusulinids, belerophons, and massive horn corals, which would make it appear to be a warm-water deposit. From this, and the fact that only very rare apatite nodules have been found, there is little likelihood that commercial phosphate deposits will be found at this horizon. This seems to be another example of the ubiquity of scattered apatite nodules in many different types of rock.

POSSIBILITY OF DEVONIAN PHOSPHATE ROCK IN PAKISTAN

In Iran, Devonian phosphate rock has been found in the Elburz Range north of Teheran. As the regional geology of this locality is not well understood, it is hard to predict whether or not the phosphate extends into Pakistan. With this in mind, Devonian rocks east of Peshawar were examined in the hope that they might be phosphatic. However, the rocks are largely made up of coral-reef lithology and cannot be considered likely to contain phosphate. Phosphate rock and coral reefs are not associated in nature, because the former is a cold-water sediment and the latter is a warm-water deposit. Even though these rocks near Peshawar are not prospective for phosphate, other outcrops of Devonian rocks to the north should be examined. An exchange of information with the Geological Survey of Iran would be highly desirable.

POSSIBILITY OF LOWER PALEOZOIC PHOSPHATE ROCK IN PAKISTAN

Pre-Permian phosphorite is present southwest of Jaiselmer in Rajasthan, India, in an outcrop several miles long. This is a new formation found by geologists of the Indian Oil and Natural Gas Commission, and its extent is yet to be determined. From its lithology--black shale, chert, and phosphorite--one can predict that it originally was quite widespread. The stratigraphic sequence from base to top consists of Precambrian rocks unconformably overlain by the Birmania Formation. The Birmania Formation is made up of redbeds at the base, which probably correspond to the Saline Series of the Salt Range. Over the redbeds is a limestone unit, and over that is the black shale-chert-phosphorite unit. Over the Birmania Formation in some areas is a boulder bed that probably correlates with the Talchir boulder bed of the Salt Range. Productus-bearing limestone is found in some places over the boulder bed. This sequence has been bevelled here and there by pre-Jurassic erosion and is overlapped by Jurassic rocks. This unconformity is angular in many places, owing to pre-Jurassic tectonism. Much of the bedrock is covered by Recent sand dunes.

The phosphorite unit, if it extends into Pakistan, will underlie the Talchir boulder beds and overlie the Saline Series. In the western Salt Range, the Talchir boulder beds unconformably overlie the Saline Series, so there is no chance of finding phosphate there. However, in the eastern Salt Range, where we were unable to visit owing to lack of time, a shale unit occupies this horizon and perhaps is phosphatic. Also, several oil well tests south of the Salt Range have penetrated dark shales at this horizon. Thus, the eastern Salt Range should be explored for phosphate. Water wells in western Rajasthan west of the known outcrop of the Birmania show that the Birmania Formation has been faulted up by a horst and lies just beneath the sand dunes. This is very close to the Pakistan border, and perhaps similar areas exist in Pakistan. Therefore, that part of West Pakistan adjacent to Rajasthan should be carefully explored. In addition, the Rann of Kutch area near Nagar Parkar is underlain by Precambrian rocks in part and probably should be checked for lower Paleozoic rocks.

SUMMARY

This reconnaissance exploration program has been far from exhaustive. Several ideas of where phosphate might be in West Pakistan were tested and an attempt to see a representative stratigraphic section in West Pakistan was made. The results were in part discouraging, and in part encouraging. It seems unlikely that the lower Tertiary-Cretaceous phosphogenic province of the Middle East extends into West Pakistan, but the Jurassic phosphogenic province of the Himalayan foothills may extend into West Pakistan. It is also possible that the Devonian phosphate rock of Iran and the lower Paleozoic phosphate of Western India extend into West Pakistan.

Recommended further program for phosphate evaluation

A further program of exploration for phosphate in West Pakistan is well justified. One job that needs doing is more careful study of some of the ground already covered in this reconnaissance. Two specific areas of work are given in detail above. In addition, several areas (also indicated in detail above) that were not covered in this reconnaissance should be explored. If new discoveries are made, an expanded program should be considered.

REFERENCES

Hunting Survey Corporation, Ltd., 1960, Reconnaissance geology of part of West Pakistan. Colombo plan co-operative project: Toronto (Report published for the Government of Pakistan by the Government of Canada), p. 1-550.

McKelvey, V.E., 1963, Successful new techniques in prospecting for phosphate deposits: in U. S. Department of State, Natural Resources, Minerals and Mining, Mapping and Geodetic Control: United Nations Conf. Application of Science and Technology for the benefit of the less developed areas, Geneva, 1963, U. S. Papers, v. 2, p. 163-172.

Sheldon, R. P., 1964a, Exploration for phosphorite in Turkey--a case history: Econ. Geology, v. 59, p. 1159-1175.

_____, 1964b, Paleolatitudinal and paleogeographic distribution of phosphorite, in Geological Survey Research 1964: U. S. Geol. Survey Prof. Paper 501-C, p. C106-C113.